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Australian Bureau of Meteorology Space Weather Services: Recent Initiatives

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SWPC Space Weather Workshop

28 April 2016

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Australian Bureau of Meteorology Space Weather Services

www.sws.bom.gov.au

- Originally **Ionospheric Prediction Service** (IPS) 1947-2008.
- 2008 Renamed "Space Weather Services" (SWS) section within Bureau of Meteorology **Hazards Prediction Branch**.
- Contact details changed office@ips.gov.au → sws_office@bom.gov.au

- **Australian Space Forecast Centre** (ASFC) team consists of
  - 4 Senior Space Weather Forecasters (SSWF's).
  - 7 Space Weather Forecasters (SWF's)
  - Weekly rotation cycle
- Move to 24/7 forecast centre coverage for significant events.

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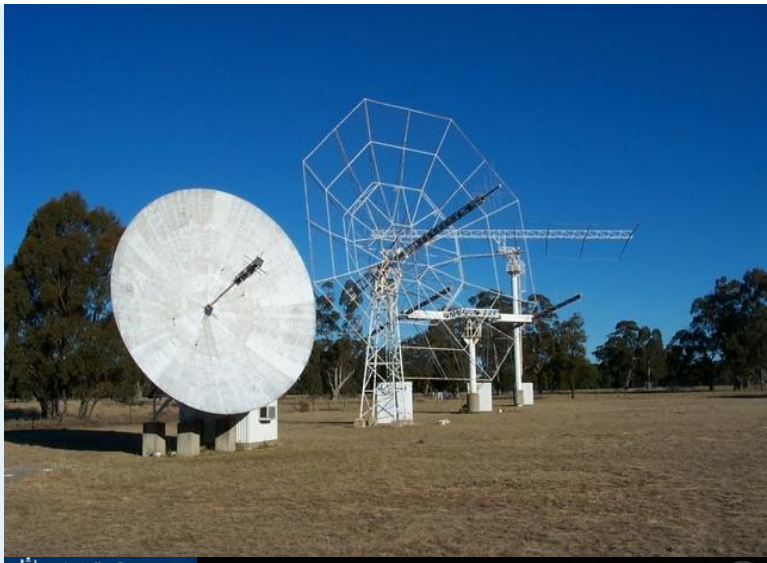
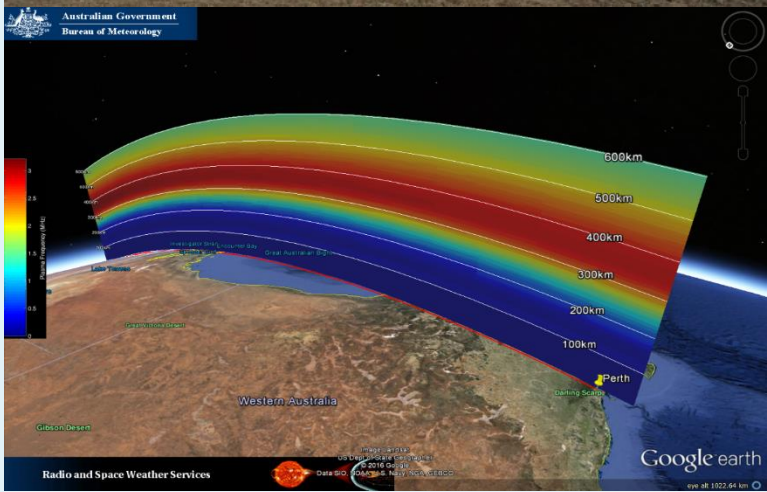
Presentation Overview

1. **Overview of Space Weather Services**
   - Space Weather Network
   - Online Services
2. **National Positioning Infrastructure Project**
3. **Ionospheric Modelling and Forecasting**
   - Data Driven Models
4. **Solar and Geophysical Forecasting tools**
   - Solar Forecast Tools
   - Severe Space Weather Model
5. **Recent engagement with …**
   - Critical Infrastructure Groups & Aviation.
   - Key Stakeholders/Industry/General Public





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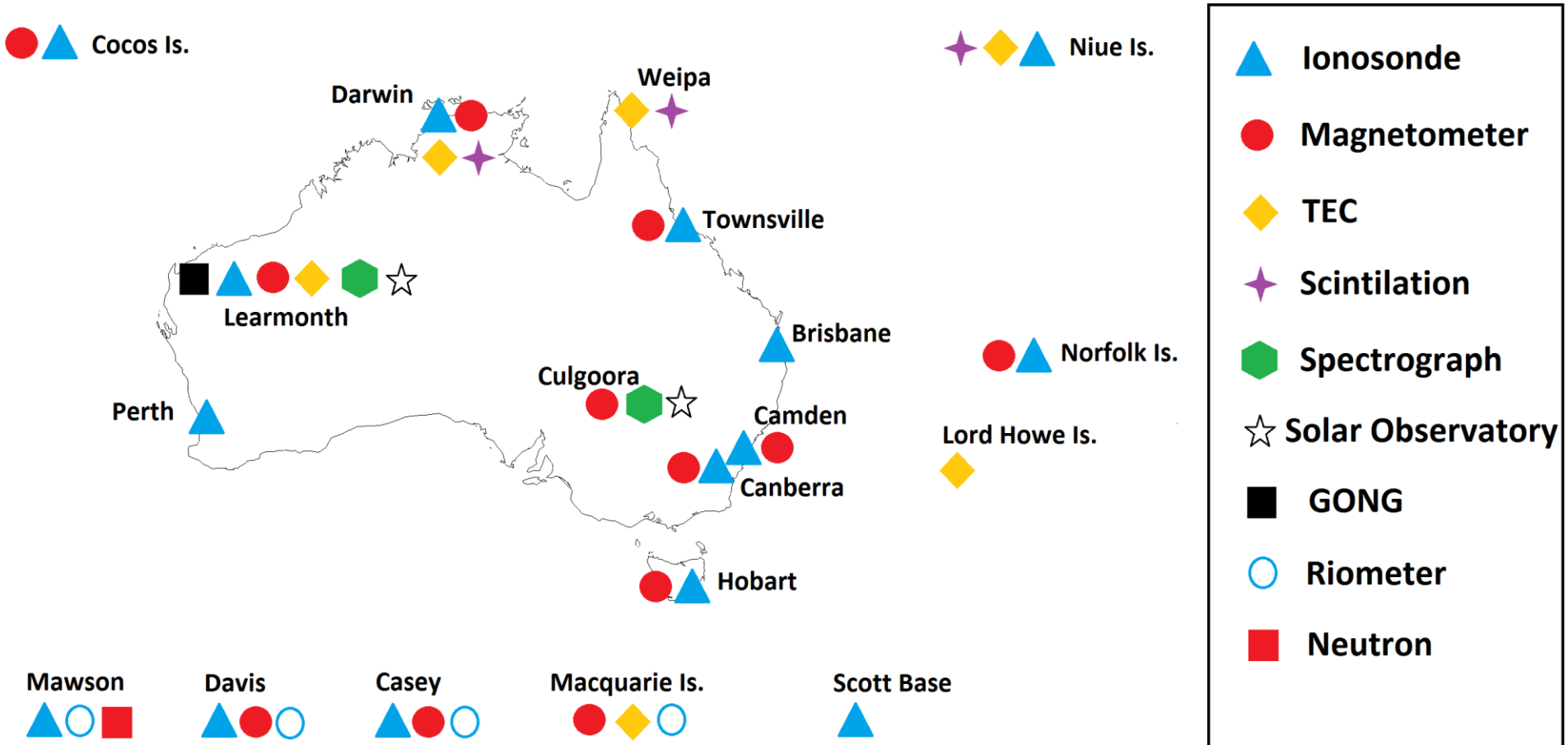
1. SWS Overview: Space Weather Network Sensors and Locations



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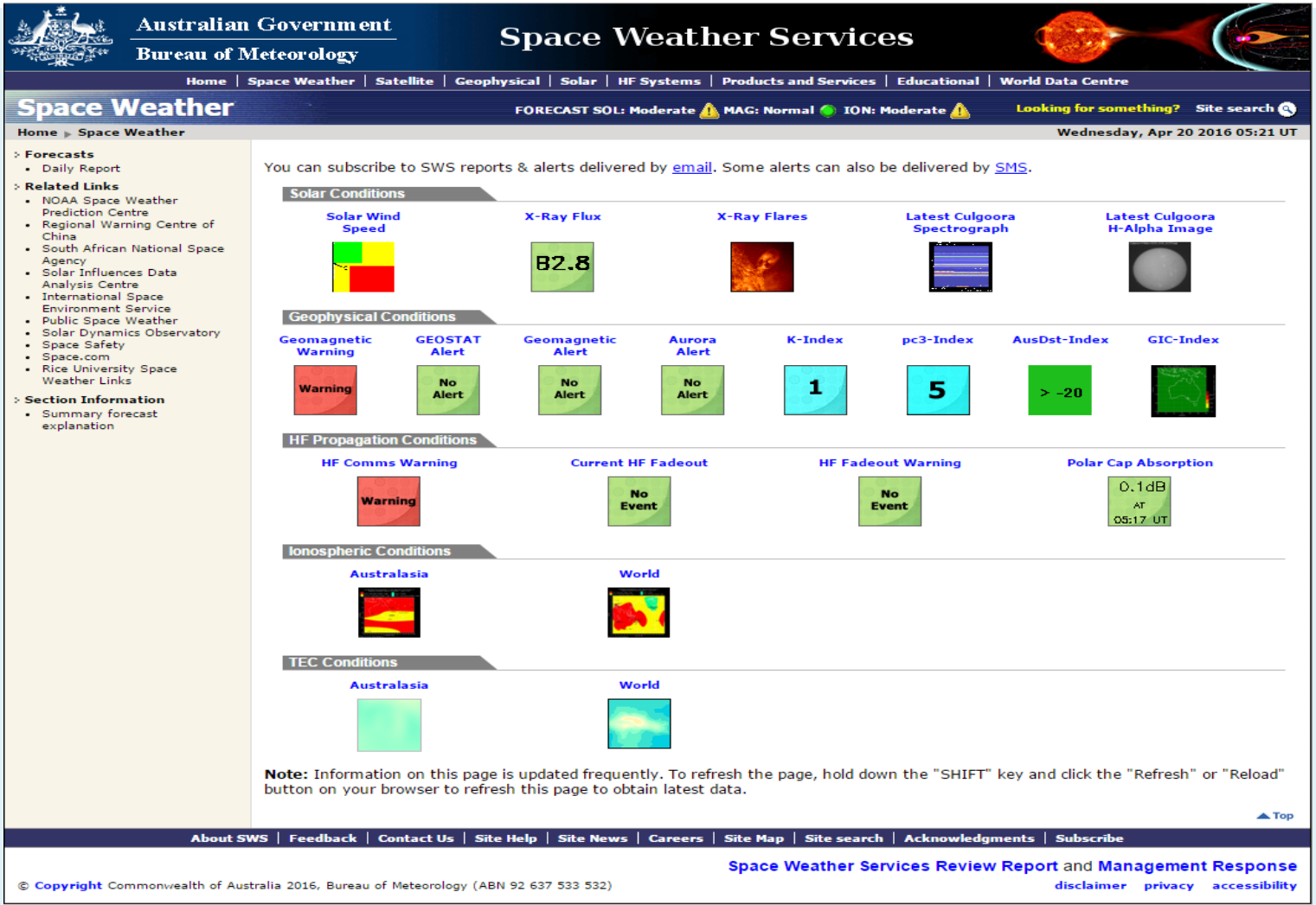
1. SWS overview: Online Products and Services



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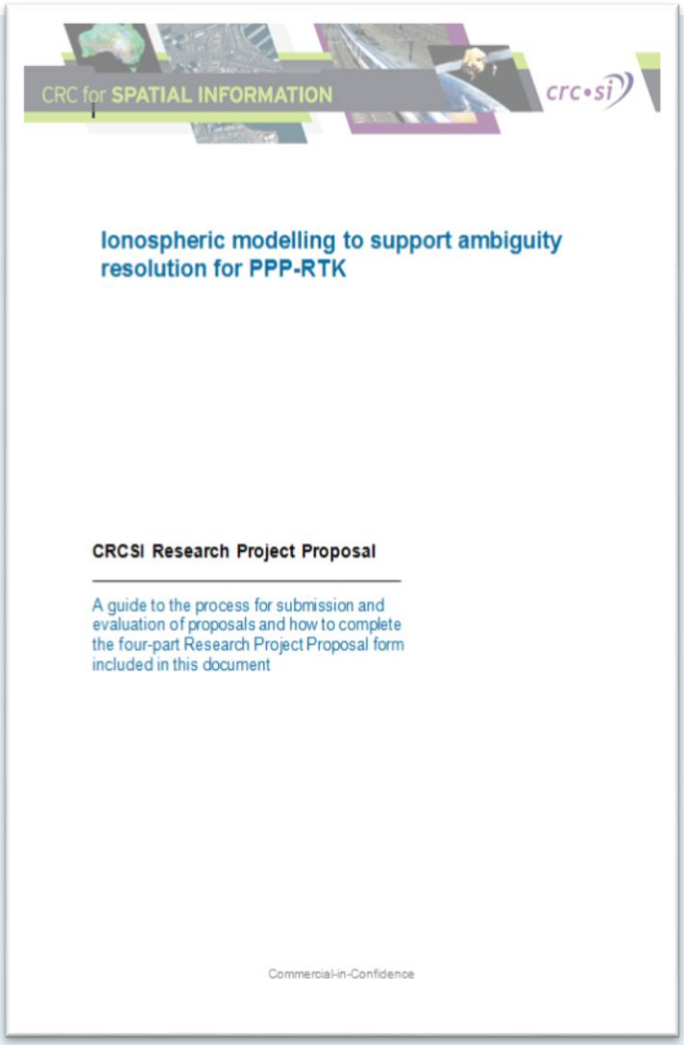
2.1 Ionospheric modelling to support the National Positioning Infrastructure

- 2.5 year research project with collaboration between
  - Bureau of Meteorology's Space Weather Services
  - Cooperative Research Centre for Spatial Information (CRCSI)
- Aims to deliver a highly accurate real time ionospheric model to support the operational implementation of PPP-RTK (Precise Point Positioning Real-Time Kinematic) for the National Positioning Infrastructure.



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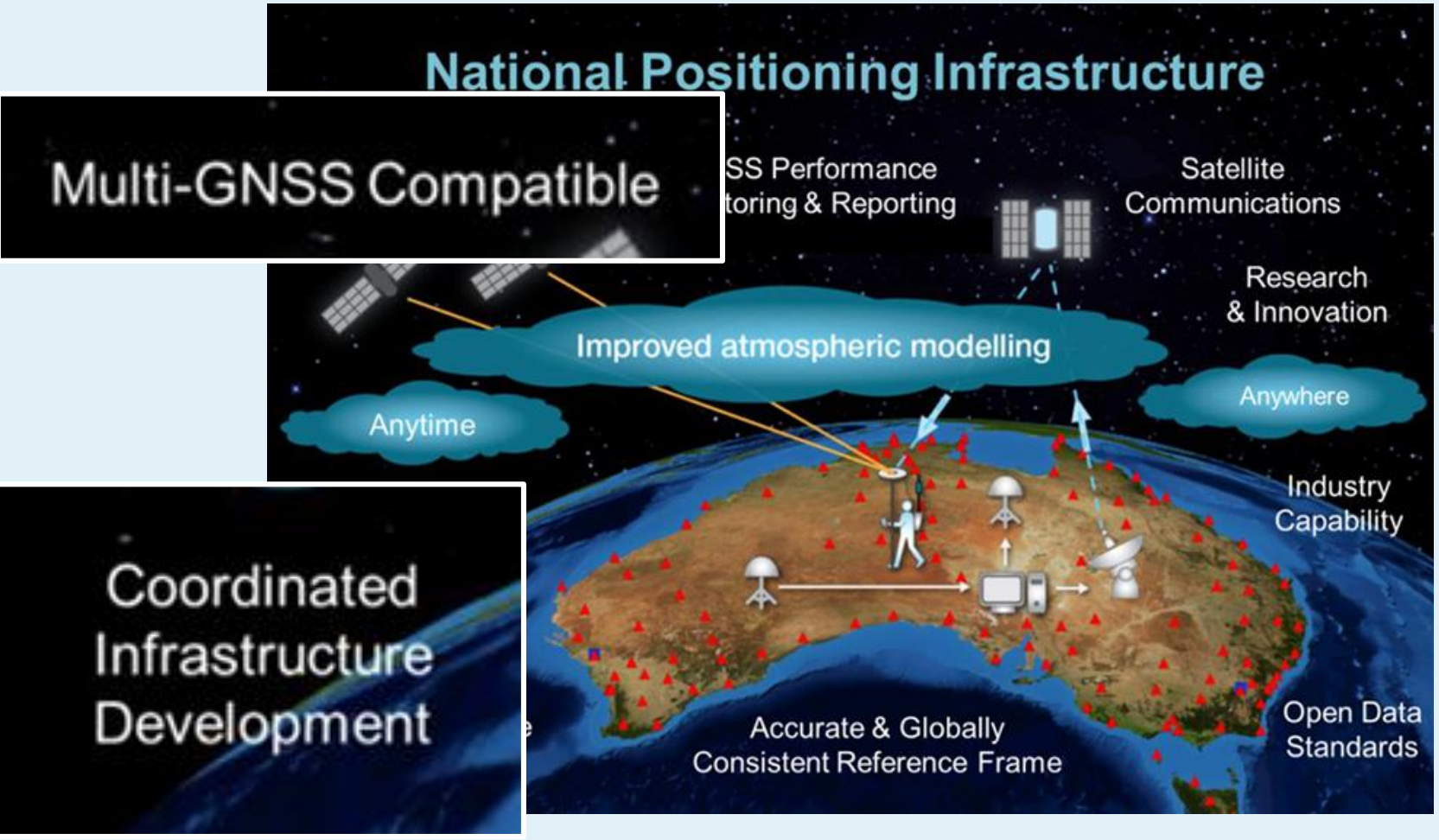
2. National Positioning Infrastructure

"Instantaneous, reliable and fit-for-purpose access to positioning and timing information anytime and anywhere across the Australian landscape and its maritime jurisdictions"



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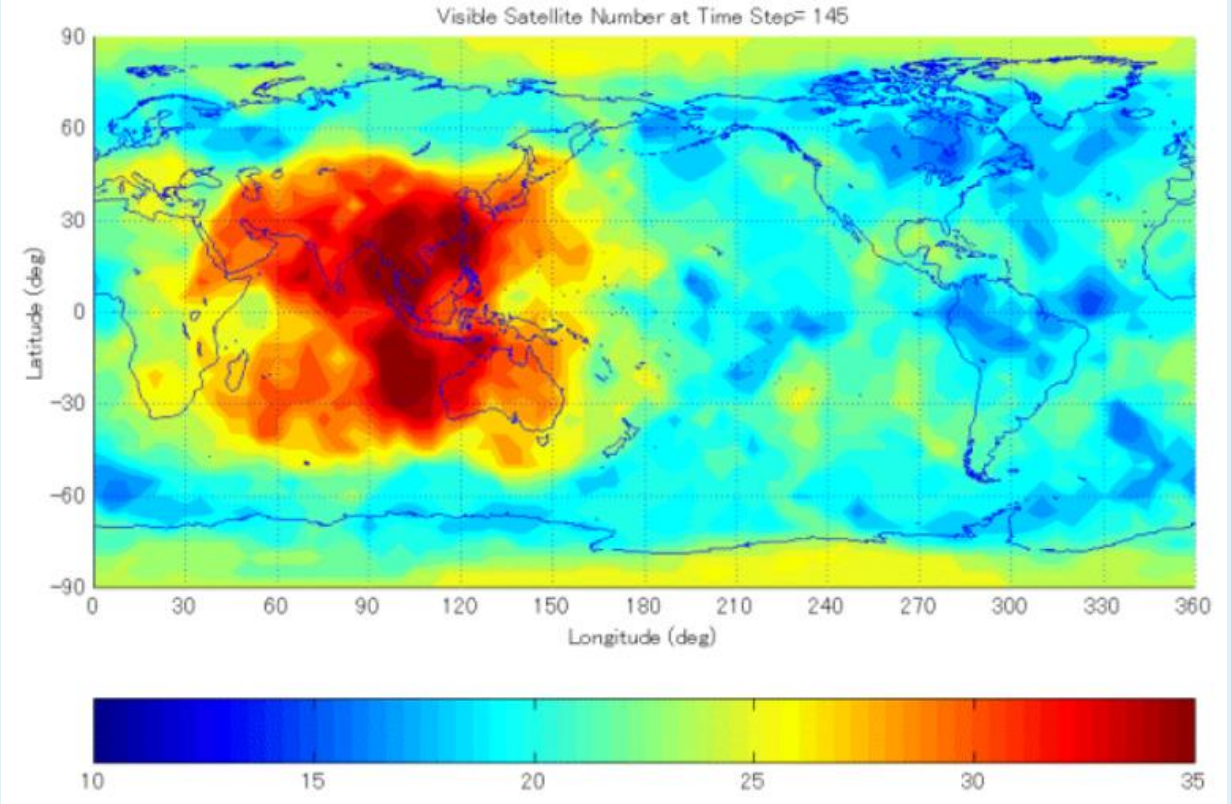
2. NPI: Multi-GNSS compatible.

- Australia one of few countries that will receive positioning signals from six systems.
  - GPS - USA
  - Beidou - China
  - Galileo - Europe
  - QZSS - Japan
  - IRNSS - India
  - GLONASS – Russia
- Multi GNSS = Faster PPP convergence



Visible GNSS satellites across the globe by 2020.
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2. National Positioning Infrastructure project

- CORS (Continuously Operating Reference Station) networks operated independently on an ad-hoc basis by state governments and industry
  - However, an Australia wide CORS network (@70km spacing) would be too expensive.
- PPP-RTK provides standard PPP users with additional information (ionosphere, ephemeris data, clock offset) derived from a reference network, enabling high accuracy & low convergence times.
  - Bottleneck though is with the accuracy with which ionospheric corrections must be provided to the user.
- Success of the PPP-RTK implementation for the NPI requires a significant improvement in ionospheric modelling accuracy over existing capability
  - precise sub-TECU ionospheric corrections required to enable rapid ambiguity resolution to achieve positioning at the level of a few cm.

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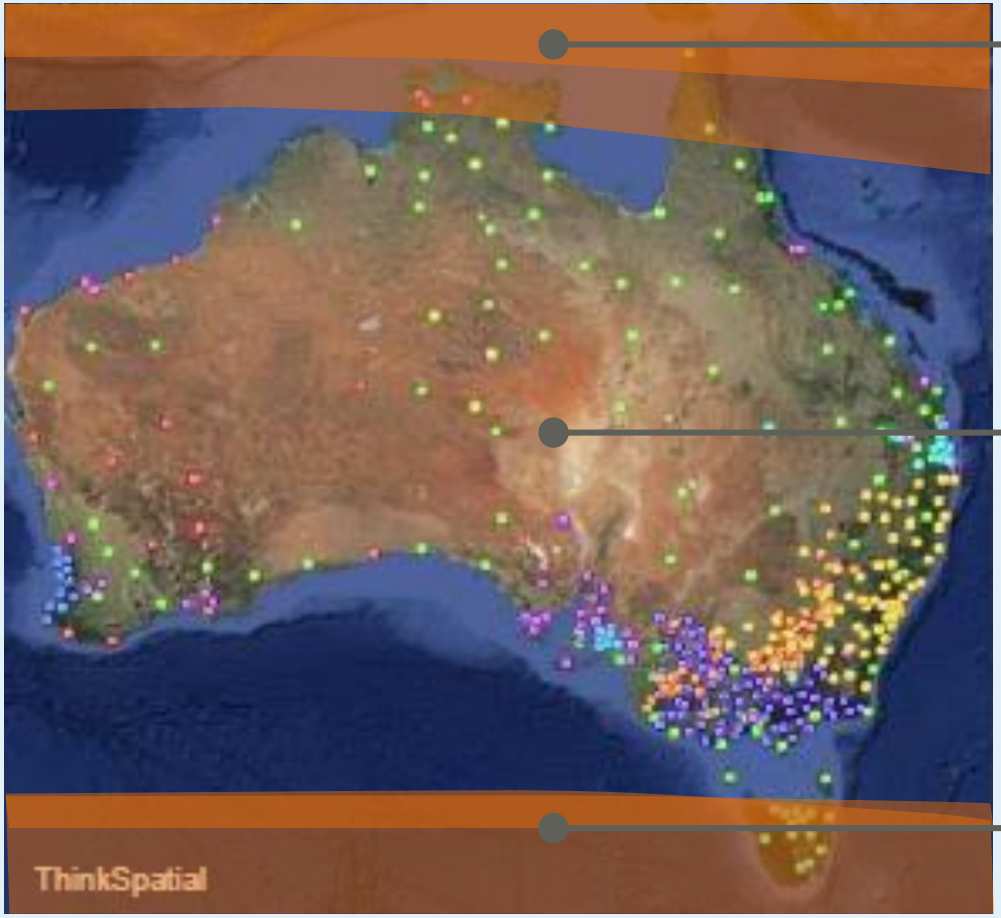
2. Ionospheric Modelling challenges for the Australian region.



Low latitudes

Equatorial Plasma Bubbles (EPB)

Large spatial gradients

Ionospheric Scintillation

Mid latitudes

Storm-Enhanced Density (SED)

Medium Scale Travelling Ionospheric Disturbances (MSTID)

High latitudes

Storm-Enhanced (Sub-Auroral) gradients

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3. Data Driven Ionospheric Modelling

- **Model types**
  - Regressions
  - Neural networks
  - Decision trees
- **Data requirements**.
  - Training / test data covers long time period (> 1 solar Cycle).
  - All model parameters required at each time point (all or none).
  - Operational data consistent with training data.
- **Benefits**
  - Simpler to develop & implement.
  - Exploits considerable archive of space weather data.
- **Limitations**
  - Availability of relevant and suitable data for training / real time operation.
  - Trend towards climatology in poorly specified models.

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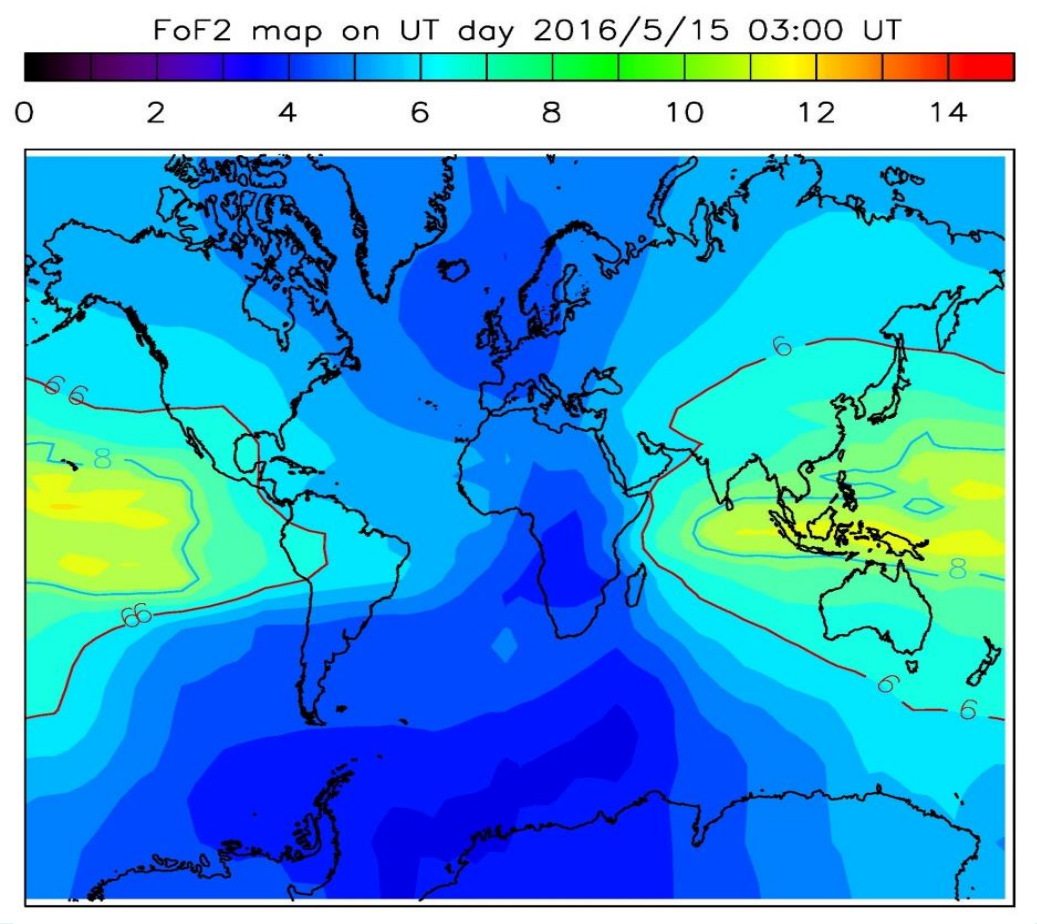
3. Quiet-Time f_0F2 model and Short Range Forecasting

- Motivation: Improvement in short term HF forecasting for the local Australian region.
- Study of data gathered from 50 years of f_0F2 observations.
  - Result: Model of non storm-time ionospheric support.
  - Support daily operations: 3 day T-Index forecast.

Further analysis into…

- Storm time behaviour and underlying trends.
- Cause and trends seen in this variability.



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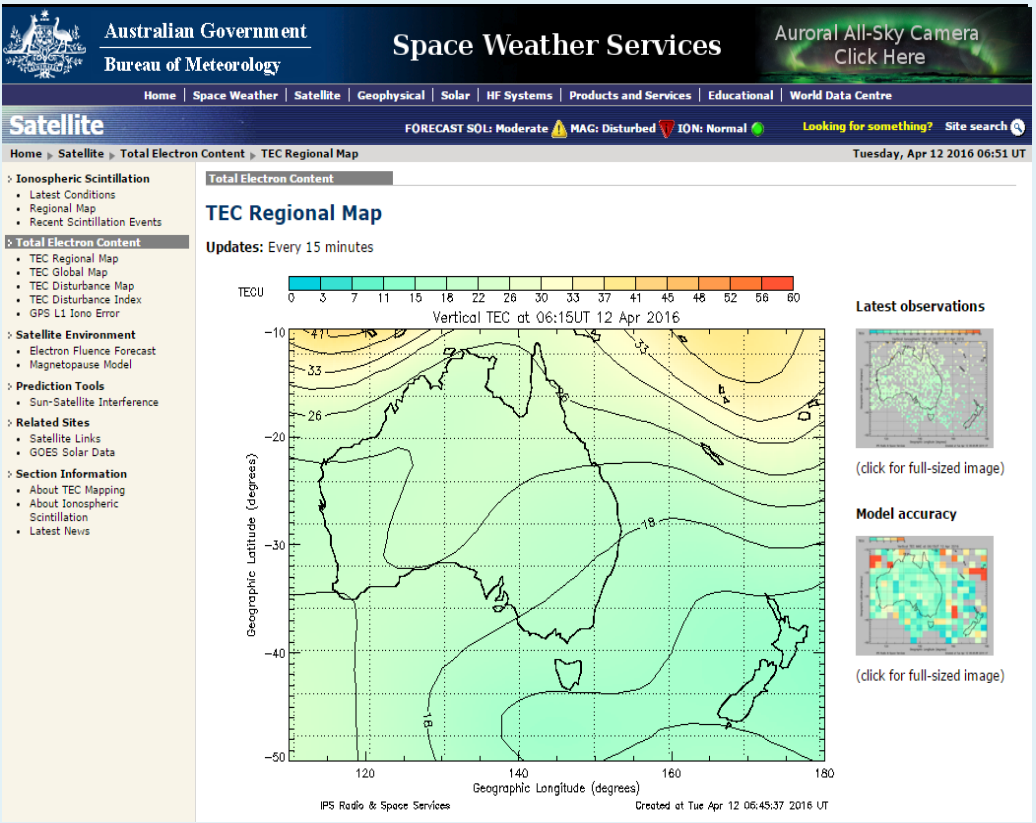
3. Regional Specific Forecasting and TEC/f_0F2

Spherical Cap Harmonic Analysis (SCHA)



- **Modeling the Australian region**
  - Top-side TEC mapping
  - Bottom-side ionospheric sounder model (Vertical and Oblique ionograms)

- **TEC/foF2 forecast model**
  - Combined use of the Principal Component Analysis (PCA) and artificial Neural Network (NN) for topside ionospheric model.
  - Utilise Neural networks due to the non-linearity of the ionosphere.

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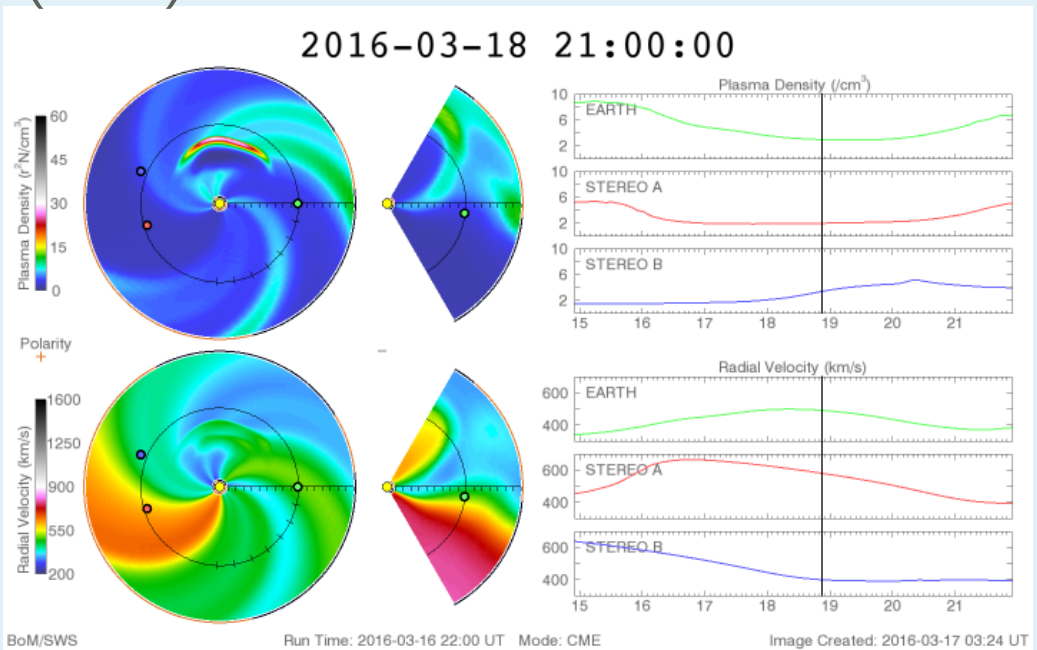
4. Solar and Geophysical Analysis Tools.

- Tools used to assist with daily forecasts and nowcasts in the ASFC…
  - Enlil (SWPC)
  - Flarecast Model (SWS)
  - Flare Probability Model (SWS)
  - Severe Space Weather model (SWS)

- **Enlil**
  - Low resolution simulations of ambient solar wind conditions.
  - CME modelling via parameters obtained from CAT tool.
  - Simulation times ~1hr (8 core Linux workstation).



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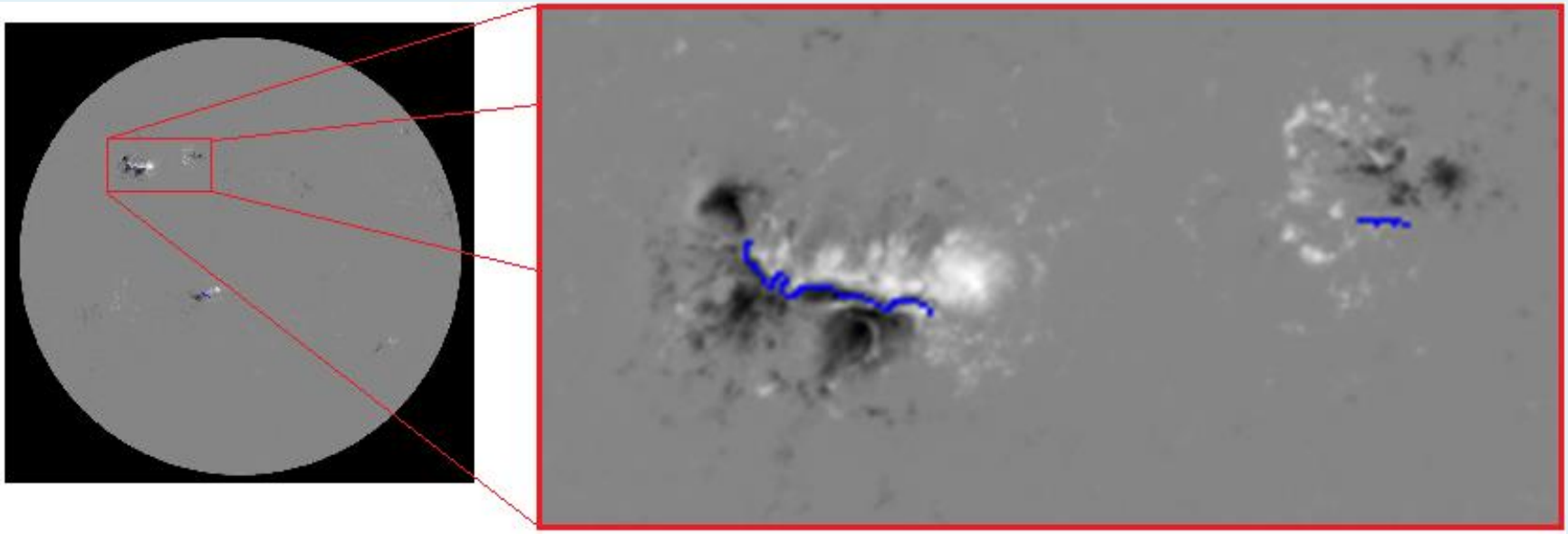
4. Forecasting Tools: Flarecast

- Automated solar flare forecast based on region characteristics
- Deterministic model: uses Solar Dynamic Observatory (SDO) or GONG HMI solar magnetograms and image processing to automatically identify active regions.
- Output is generated in near real-time as new input data becomes available.
- Many different parameters of the active region and the neutral lines are estimated.
- Estimates capability of a region to produce M, M5+ or X-class solar flares.



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4. Forecasting Tools: Flare Probability Model

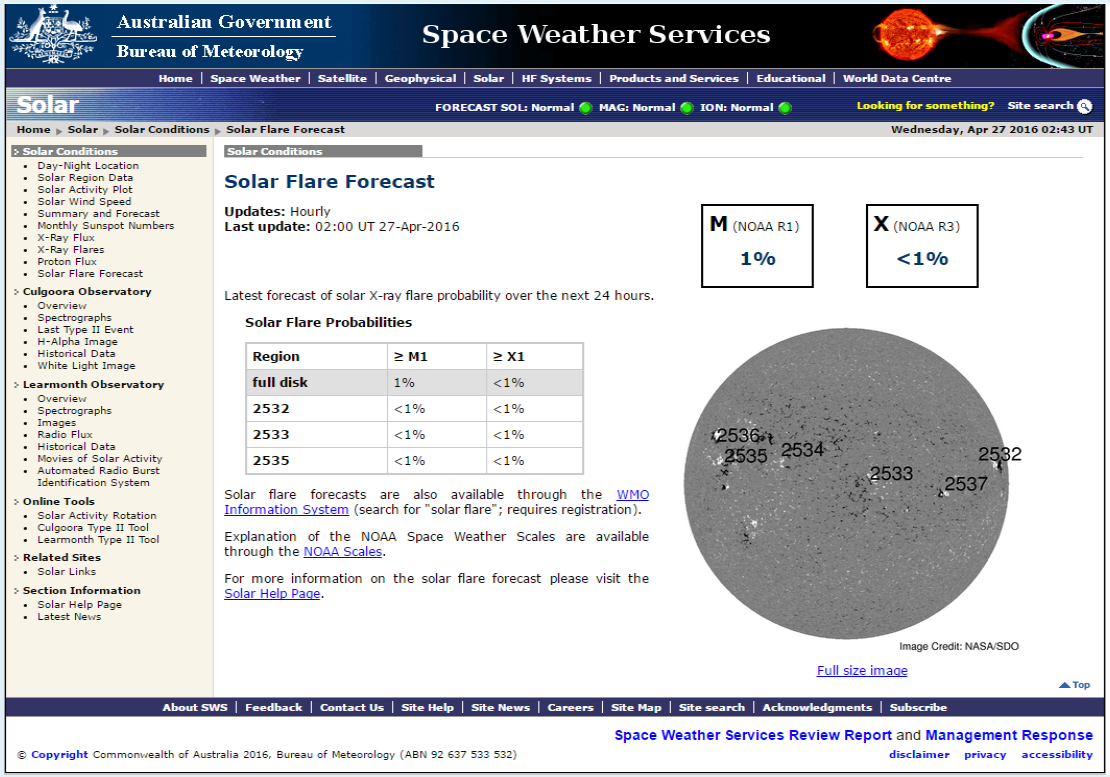
Statistical Model: to estimate the probability over the next 24 hours of an X-ray solar flare ≥ M1(≥ X1) in magnitude (peak flux)

Flare Probability (%)

	M	X	Mag	Zur	Area	Now at...
2389	1	1	β	Dso	50	S10 E06
2390	2	1	β	Dac	190	S16 W24
2391			α	Hsx	50	N06 E60
DISK	3	1				

Model selection is based on data availability, using all or a subset of these region characteristics:

- Location
- Classification
- Area / areal growth rate
- Number of spots
- Magnetic complexity
- Magnetic characteristics (length of neutral line, maximum N-S magnetic gradient, ++)
- Recent flaring history



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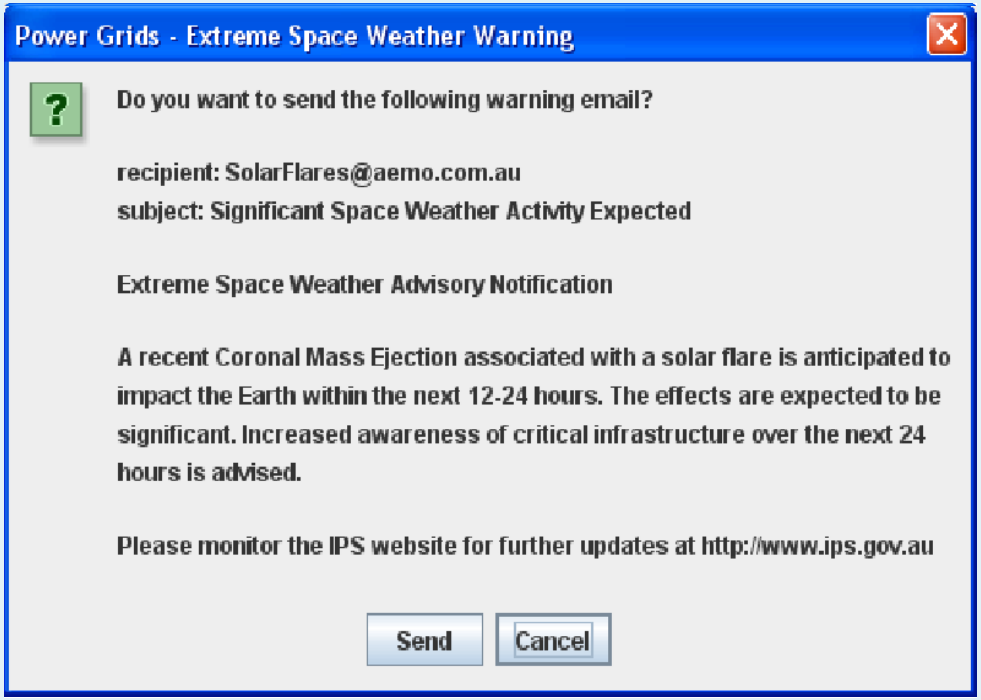
4. Forecasting Tools: Severe Space Weather (SSW) Model

- Operational GUI used within the ASFC.
- General linear statistical model as a back-end, providing both binary and probabilistic forecasts for SSW
- Inputs include...
  - Location of active region on solar disk
  - X-ray flare magnitude/duration
  - Presence of halo CME (CME width)
  - CME speed
- **Prediction of D_{st} < -250nT**



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5. Critical Infrastructure Groups: Severe Space Weather events

- Australian Energy Market Operator (AEMO) manages both wholesale and retail markets in electricity and gas across all of Australia (one of few worldwide)
- In-situ sensors for GICs (observed in both power grids and pipelines)
- SWS has implemented Severe Space Weather Warnings as an integral part of mitigating procedures for power networks
  - Development of the GIC-index, to quantify periods of GIC activity
- Modelling the power grid response to space weather storms is intended to form part of the mitigating procedures and is a work in progress

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Date/Time (AEST)	Who	Event/Action
1102–1302 21 June	Bureau	A long duration solar flare was observed peaking at 1236
21 June	Bureau	Type IV radio emissions observed
21 June	Bureau	Earth directed plasma cloud or Coronal Mass Ejection (CME) confirmed with satellite imagery from the SOHO satellite
21-22 June	Bureau	Modelling and analysis of event indicate possible severe event—predicted time of arrival estimated to be 0600 23 June
1439 22 June	Bureau	Severe Space Weather WATCH issued
1457 22 June	AEMO	Issued market notice 49199—Severe Space Weather Watch
0359 23 June	Bureau	CME observed by ACE satellite
0407 23 June	Bureau	Issued a Severe Space Weather WARNING for short duration GIC
0435 23 June	Bureau	Peak GIC-index observed across space weather network monitors
0435 23 June	AEMO	Observed peak transformer neutral currents in power network
1425 on 23 June	Bureau	Observed storm peak—estimated Australian Dst-index of -236 nT
23 June	Bureau	Analysis of further Earth directed CME activity with predicted time of arrival of 1000UT on 24 June—severe warning window valid for 72 hours from initial time of issue
1446 25 June	Bureau	Severe space weather threat passed - issued Severe Space Weather warning CANCELLATION notice
1508 25 June	AEMO	Issued market notice 49206 - Severe Space Weather Watch cancellation

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5. Aviation Space Weather strategy

To enable space weather products produced by the Bureau to be more specific and relevant to the aviation industry

- Aviation focussed user workshop planned for the second half of 2016
- Focus on
  - working with the aviation industry to tailor current products & services (impact focussed)
  - Identify un-met aviation user needs.
  - Determine need for specific space weather products through a common portal with Bureau's Aviation Weather Services.
- Short term: Space weather training for aviation meteorologists
- Longer term: Develop products and services addressing user requirements identified in consultations

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5. Recent Customer Engagement

- 2014: Review of Space Weather Services
- Positive recommendations from reviewers, review committee and small number of key stakeholders.
- Nov 2015: SWS staged its inaugural Space Weather Users Workshop.
- Interaction with over 100 stakeholders + members of the general public.

- January 2016: customer survey distributed through via email, feedback was received from over 700 customers.

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Thank you…

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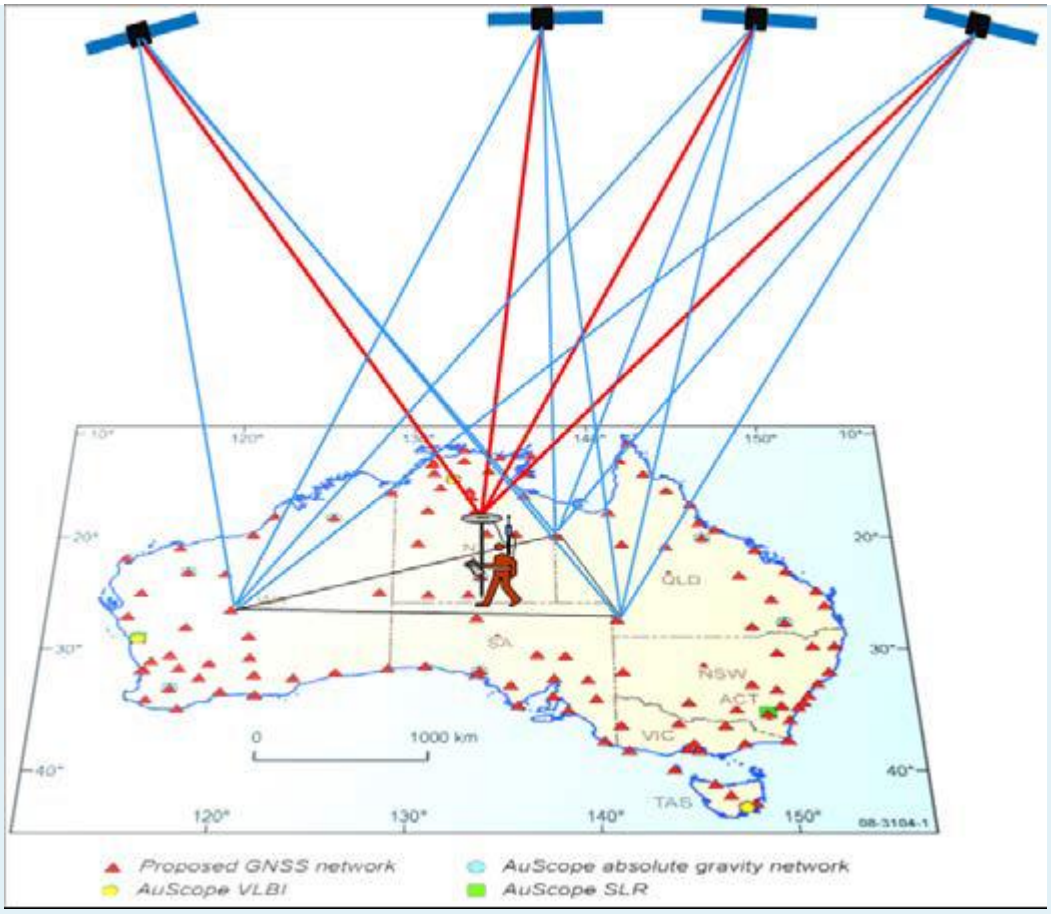
Extra info/graphics on NPI (spare)



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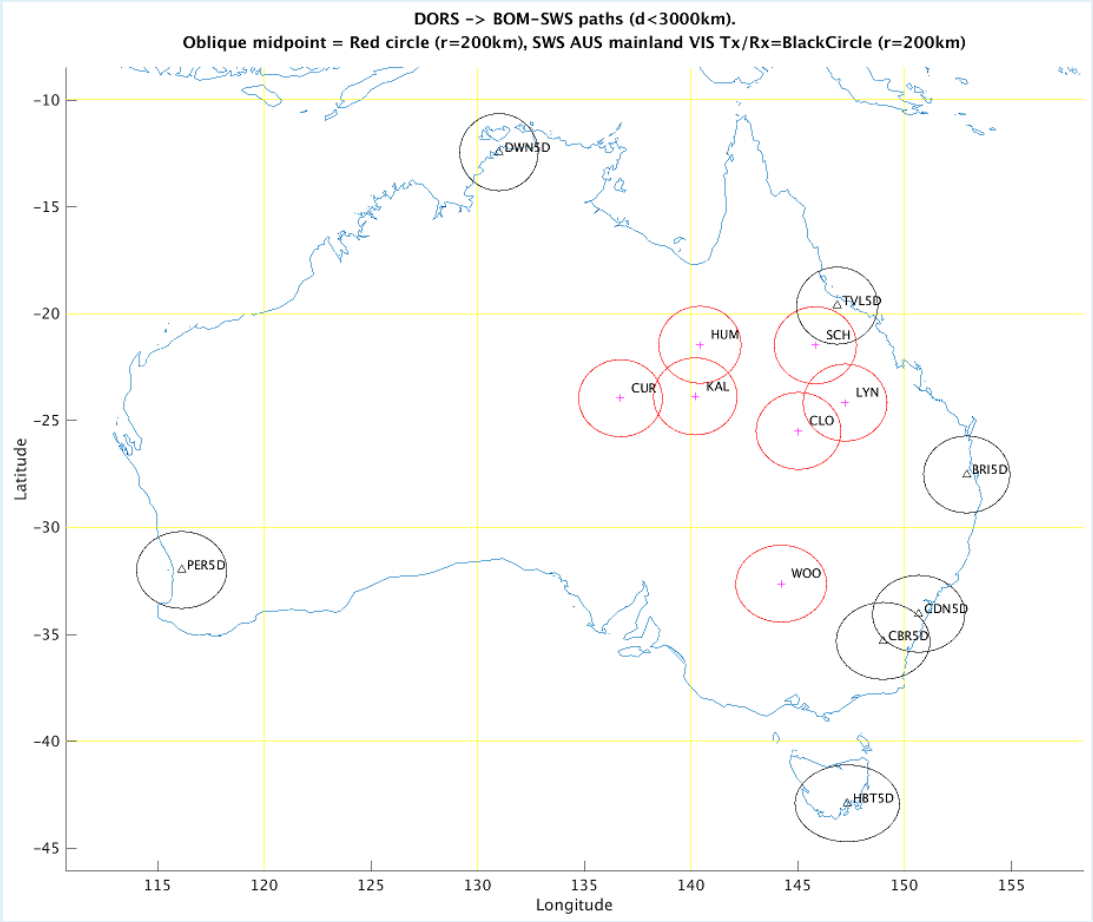
Data driven Ionospheric Modelling

- Trialing use of both Vertical and Oblique ionograms
- 7 Vertical Incidence Sounders (VIS) on the Australian mainland, 7 Oblique paths.
- On loan from Australian Defence Science & Technology Group, Digital Oblique Receiver System (DORS).
- Data fed into ionospheric SCHA model
  - Increased spatial resolution of real time ionospheric maps.
  - Observation of MSTID's.